SCIENCE

FRIDAY, FEBRUARY 11, 1916

CONTENTS

MSS. intended for publication and books, etc., intended for review should be sent to Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE DEPENDENCE OF PROGRESS IN SCIENCE ON THE DEVELOPMENT OF INSTRUMENTS[1]

OUR civilization is requiring for its physical welfare a more and more intimate knowledge of nature's forces. It is demanding this knowledge faster than it is being produced as a by-product in our educational institutions. Scientific investigation is becoming a large business. Governments have established research laboratories; private individuals have endowed others; universities are making more strenuous efforts than ever to encourage research and to make it a real part of their function; and commercial enterprises are finding it profitable to establish research laboratories on a large scale, not being able to wait for the random discoveries from other sources. These facts, alone, show that science is rendering an indispensable service.

The factors which are involved in the solution of scientific problems are in part mental and in part physical. Long experience has taught that however much we may owe to the great minds that evolve basic generalizations and hypotheses, real progress in science ultimately rests on the establishment of facts. Our reasoning faculties, by themselves, are unable to cope with the complexity of the physical world, and are sure to stray from reality unless they are continually guided by observation and experiment. Galileo with his experimental methods contributed more to sci-

[1] Address of the vice-president and chairman of Section B—Physics, American Association for the Advancement of Science, Columbus, December, 1915.

ence than did all the generations preceding him.

Observations made with our unaided senses limit us to the most superficial aspects of natural phenomena; but when we bring scientific instruments to our aid, we throw off these limitations. Not only are we enabled to observe more accurately and more systematically all that our senses ordinarily perceive, but we become endowed with new senses that open up fields of knowledge of which otherwise we could not even have dreamed. This broadened vision constantly brings to light new problems for solution, necessitating new methods and greater refinement.

The greater the advancement in any branch of science, the greater must be the development of the apparatus that is employed. The two are necessarily interdependent. The instrument is to a great extent an index of the state of the science. The greater the precision with which we can make our observations and measurements, the surer we are of keeping on the right path in our interpretation of the phenomena concerned.

I desire to lay some emphasis on this close relationship that exists between the evolution of our ideas and the development of instruments used in science, and I wish to make some suggestions as to how greater efficiency in our work may be attained.

My first purpose will be accomplished by some citations from the history of our science. Let us first recall some simple cases in optics.

Converging lenses are said to have been found in the ruins of Nineveh and must have been made long before the manufacture of glass. They were certainly used at an early date by the Greeks. But the discovery of the combination to form a telescope was not made until 1608; and Galileo soon after constructed telescopes magnifying 30 diameters, which at once led him to important discoveries. The compound microscope originated at about the same time. Without achromatic lenses, both of these instruments were very imperfect. The possibility of making an achromatic lens occurred to Newton, but reliance on a single unfortunate experiment led him to discard the idea. The construction of such lenses by Dollond, in 1757, marks the beginning of a great epoch in the development of optical instruments. It is only necessary to mention the gradual development of various combinations of lenses to bring to mind a great array of most important discoveries which they have made possible, not only in physics, but also in astronomy, in biology, in medicine, and in every natural science.

The pin-hole camera, which led to the idea of photography, was devised in the second half of the sixteenth century. After the image was rectified by means of a mirror and its sharpness and brightness increased by substituting a lens for the pin-hole, this was used quite generally by landscape painters. What flight of imagination to believe that that observed image could ever paint itself! If the idea occurred to some it was brushed aside as a fancy and a dream. Such an accomplishment must forever be beyond the reach of man! No manipulation of machinery could bring about such a marvel. No known forces of nature could be employed. But, as often happens, means were soon found, and what had been considered impossible was realized.

Even before the discovery of the camera obscura the alchemist Fabricius (1556) made silver chloride, and observed that light blackened it. He found that an image of an object imprinted itself upon it. This had no significance to him, how-

ever, and the discovery, although published, was for the time forgotten. More than two hundred years later (1777), Scheele made images imprint themselves on paper that had been saturated with a solution of silver chloride, but these images disappeared when exposed to light. Finally, Niepce, in 1827, produced permanent photographic pictures on metal, and Daguerre improved the method in 1839.

Becquerel and Draper in 1845 independently photographed the Fraunhofer lines, this being the first application of photography to scientific research. Since that day photography has become one of our important new senses and an indispensable instrument of research. Even the long-sought color photography is now a reality.

Spectroscopy presents a good illustration of our subject. That rainbow colors are produced by edges of glass plates was known from the beginning of the Christian era. Glass prisms were manufactured in the seventeenth century, and attempts made to explain the production of the colors resulted in the solution given by Newton, in 1672.

Wollaston, in 1802, observed seven dark lines in the solar spectrum, but Fraunhofer by making larger and better prisms and by using a telescope was enabled to see "countless" numbers of them. He also discovered the bright line spectrum of sodium, superposed, however, over the continuous spectrum of the heated carbon particles present in the flame. He was also the first to make and to use the diffraction grating and to measure the wave-length of sodium light. No explanation of the dark solar lines was given, however, for forty years. After the invention of the Bunsen burner in 1857 many substances could be easily vaporized, and spectral lines were obtained free from the continuous spectrum which confused previous experimenters. Thus spectrum analysis was developed, and the true nature of the dark lines in the solar spectrum soon afterwards demonstrated. The possibility of detecting the motion of stars by the shifting of the spectral lines was considered. This, however, could not be done with the instruments then available. Nothing more could be accomplished until diffraction gratings were much improved.

The original gratings had been constructed of wire, and later they were made with scratches on glass. These were soon perfected sufficiently so that in 1868 Huggins detected the shifting of the dark lines in stellar spectra, beginning a new era in the study of astronomy. The further perfection of these gratings has been most remarkable and the results obtained with them of the highest importance. Even now we feel the need of a still higher resolving power. The problem was, and still is, to get the lines equally spaced with sufficient accuracy for a large number of successive lines. In about 1870, the Nobert gratings, previously used, were replaced by those of L. M. Rutherfurd (1816–1892), who finally made gratings on speculum metal, with a resolving power of 10,000. Rowland (1841–1901) then succeeded in making gratings with a resolving power of 150,000, which advance revolutionized spectroscopy. The gratings now made with the Rowland engine have a resolving power of about 400,000, and the 10-inch Michelson grating, 600,000. These recent improvements in the ruling of the grating, with the added aid of photography, are extending far the limits of a fertile field of research and amassing valuable data for the ultimate demonstration of atomic structure. The time taken through a long number of years to construct an accurate screw was most profitably spent. The same amount of time employed in the taking of observations, in

making hypotheses, or in formulating generalizations, could not have produced results of like significance. It is to be hoped that the probable limit attainable by the present method of construction may be reached, and that we may soon have a 20-inch grating with a resolving power of more than a million.

A technique for making metallic replicas of gratings is highly desirable and should be attempted. The few good gratings that can be obtained only after years of painstaking preparation should be indefinitely reproduced.

Turning for a moment to the subject of temperature, we find that the first thermometer was devised by Galileo and consisted of a glass bulb with an attached tube whose end dipped into water. It measured temperature changes with an accuracy far greater than our heat sense could estimate it, and was truly a wonderful instrument. It made the sense of sight serve the function of the heat sense, and did it better. The original instrument was affected by changes of atmospheric pressure and had an arbitrary scale. These defects were gradually overcome. The bulb was filled with water and the tube sealed. The present fixed points, after many others had been tried, were finally adopted. Mercury was selected as the most suitable liquid for general purposes. The material of the bulb has received due attention, and many modifications of the thermometer for various purposes have been devised. It is doubtless the most common scientific instrument in use. The development of the mercury thermometer has made itself felt in every line of research.

Other means for measuring temperature have been devised. Resistance thermometers, thermocouples, bolometers, and a variety of radiation pyrometers, have made possible investigations beyond the reach of the mercury thermometer.

The development of the nitrogen thermometer and of the thermodynamic scale has placed temperature measurements on a still more scientific basis. The thermodynamic scale has quite recently been extended to 1,550° Centigrade; and all measurements beyond that are still extrapolations based on the law of the thermocouple up to the melting point of platinum (1,775° C.), and on the two laws of radiation for higher temperatures.

The range of temperatures at our control for the study of natural phenomena extends from about two degrees Centigrade above absolute zero to 4,000 degrees, the outer limits being attainable through the invention of the liquid air machine and the electric arc. The oxidation of all materials at high temperatures has made the use of the electric arc impossible for most purposes. A recently devised furnace has overcome this difficulty, enabling experiments to be made in any gaseous atmosphere up to 1,600 degrees Centigrade; and also produces any temperature nearly up to that of the electric arc. The bombardment by cathode rays gives promise of the development of extremely high temperatures for experimental work in a vacuum. The attainment of the lower limit of temperatures has made possible the most wonderful discovery of "superconductivity," which, with the investigations on conductivity at high temperatures, adds most significant data toward the development of the theory of electric conduction.

The bellows, the siphon, the water pump, the fact that water is supported in a filled inverted bottle when its mouth is in water, and various other phenomena, were explained on the principle that "nature abhors a vacuum." The invention of the barometer by Torricelli (1643) almost

immediately enabled Pascal (1647) to prove the falsity of this principle and to establish the correct foundation for the theory of hydrostatics.

The invention of the air pump made possible a whole series of investigations. Recently we have been impressed with the invention of several forms of pumps which enable us to obtain very high vacua with great ease and rapidity. The importance of such appliances must not be overlooked. Time is a most important asset for the investigator.

I wonder whether we appreciate what we owe to the great accessibility and continual improvement in manufactured materials. What a luxury we have in insulated wire! How could we do without glass tubing! We recall with what difficulty Pascal procured a tube for repeating Torricelli's experiment. Now we have even quartz tubing and quartz vessels of all kinds. The recent discovery of producing tungsten in a ductile form has made that element indispensable for some purposes. Fibrox, a new material not yet purchasable, is an improvement on all heat insulators. Manganin wire, with its application to all kinds of electrical instruments, has made electrical measurements of high precision comparatively simple. But it is not necessary to enumerate further.

Turning now to electricity for our examples, we find that the electroscope has developed from the pith balls and the simple gold leaves into a variety of very sensitive instruments, and the Thomson quadrant electrometer, into that of Dolezalek. The string electrometer makes it possible, for the first time, to measure rapid changes of a charge.

One of the great conveniences of a modern laboratory arises from the high state of perfection of current-measuring instruments. Galvanometers which are already highly developed are still continually being improved. In the moving coil galvanometer higher sensitivity is being attained, and efforts are being directed specially to obtaining a greater constancy in the zero reading and a greater uniformity of the radial field. The development of the galvanometer and of the methods of its standardization are of extreme importance to research.

The electric condenser, which was first made without regard to absorption, has gone through the stage where it was considered an improvement to saturate the dielectric with moisture, then where, in the process of construction, the condenser was boiled in a vacuum; to the present method of boiling at the highest possible temperature, and then subjecting to high pressure. Many problems in the development of the condenser still remain to be solved. The better elimination of the absorbed charge would add greatly to its use as a precision standard for the measurement of the electric quantity, and would be of great importance wherever condensers are employed with alternating currents.

The recent developments for excluding moisture from resistance coils, and for rendering them free from capacity and self inductance, show that advancement even in the construction of resistance standards is still in progress.

The Crookes' tube has resulted in the discovery of the X-rays, which are now proving of such great service not only in medicine, but in the study of atomic structure and of atomic distributions in crystals.

The human voice was first transmitted by electricity in 1876. The rapid conquest, since that time, of the almost insurmountable obstacles of long-distance telephony has been due to progress in many lines of research and to the large number of workers striving for the same end. The present

transcontinental telephone line is 3,400 miles in length and transmits speech without distortion. The chief factors that have contributed to this result are the Bell receiver, the microphone, the coils for preventing voice distortion, and finally the invention of the thermionic amplifier.

The twenty-fifth day of January of this year marks the beginning of transcontinental telephony by wire and September 29 that of transcontinental telephony without wires, both great achievements having been accomplished in our own country and since our last annual meeting.

The experimental proof that the condenser discharge is oscillatory and Maxwell's (1831–1879) theory of electromagnetic waves led Hertz (1857–1894) to devise the apparatus which demonstrated the existence of such waves. The value of these purely scientific efforts is seen in the result. It was found that connecting one end of the vibrating system to the earth and the employment of long antennæ improved the sending power of the transmitter; and the development of detectors improved the receiving apparatus. We have then, as applications, the wireless telegraph which is rendering such unusual service; and finally, with the development of the thermionic amplifier, already mentioned, the wireless telephone which has so recently enabled the human voice to travel across our continent and beyond to Honolulu, a distance of 4,850 miles.

A modest-looking little bulb containing a stream of almost inertialess particles known as the thermionic current would hardly have been suspected of being able to bring about, as it has, so important a step in the development of long-distance telephony of both kinds. By means of this little instrument, or rather many of them, the energy of the original telephonic current can be increased many billion times, which is then transformed, in part, into ether tremors and sent in all directions across oceans and continents and there transformed again, reproducing the original speech without distortion. Our sense of appreciation seems to have been hardened by many and great successes. We seem to be stunned, unable to comprehend fully the significance and the greatness of such a marvelous achievement.

Apparatus has been devised for the counting of both the alpha and the beta particles, and the existence of atoms has been demonstrated beyond question. The simplicity of the apparatus devised by C. T. R. Wilson for making visible the paths of the alpha and the beta particles, atoms and the minute pieces of atoms, makes us wonder whether anything is impossible, providing we have the genius to devise the proper instruments.

Radioactive substances would be exploding with stupendous violence, and their quivering atoms be sending ether pulses into space, a whole world of great activity about us, and we should be in complete ignorance of it, were it not for the electroscope and the photographic plate.

As was intimated at the beginning, this partial summary has been presented mainly for the purpose of illustrating the extent to which the development of instruments has been a contributing factor in scientific progress. It is to be noted that in many cases advancement can proceed to a certain point and then must necessarily stop, no further significant progress being possible until some required instrument of research is perfected or an entirely new one devised. It is often more profitable to devote time to developing instruments than to the continuing of investigations whose results become obsolete as soon as the instruments employed are improved. The painstaking observations of Ångström, notwith-

standing their great value, were discarded as soon as better gratings were produced.

The simplest of instruments have often been the means of making great discoveries. Faraday and Henry worked with the most simple tools. Many discoveries as far reaching as any will again be made with the simplest apparatus; but advancement in other directions can only be effected after the highest possible development of instruments and processes.

Some men by devising what appeared to be a little improvement in a machine have indirectly advanced science more than would many painstaking investigations. Instruments like the Crookes' tube lead to the discovery of facts that were entirely unsuspected and unsought; and similarly many instruments have been developed for one purpose and then found to be of value in an entirely different field. We have seen many problems solved which at first appeared beyond the possibility of demonstration or accomplishment. There seemed no possible method of approach. There were no instruments with which the results could be attained. Photography, wireless telephony, counting atoms, and seeing the tracks of atoms and of fragments of atoms, are some of the accomplishments which not so many years ago would have been considered beyond the range of possibility.

Many instruments are used as tools to perform certain definite functions in a more complex system, and, as such, should be so constructed as to require the least possible attention. As far as it is practicable the instrument should read directly the quantity desired. We already have many such instruments, as, for example, the ammeter, voltmeter, fluxmeter, potentiometer, Wheatstone bridge, direct reading spectrometer, and the recently devised instruments for giving directly the length of electromagnetic waves and their logarithmic decrement. The "artificial eye," also recently devised, gives in the photometry of colors results equivalent to that of an average eye, eliminating the necessity of several observers. In the measurement of conductivity an apparatus has been so assembled as to give directly the resistance in microhms per cubic centimeter. Self-recording instruments of all kinds are a great convenience and in many operations practically indispensable.

The intricacy and difficulty of many operations which often retard progress should be removed as far as possible. Every instrument improved to give greater convenience and greater simplicity in operation, makes it possible for all who use it to concentrate their whole energy on that part of their work which has real significance. This adds much to efficiency and productivity in science.

I wish to emphasize the importance of using the best and most convenient instruments obtainable for any given purpose. We may learn from manufacturing establishments the advantage of discarding apparatus that has become obsolete or not suited for our particular purpose. In no other way can our output become what it should be.

There are many problems pressing for solution, and every unexplained phenomenon may hold in store still more problems or strange relationships and unknown entities. Most of the solutions can be made only with the aid of scientific instruments.

We want to know something definite about the nature of gravitation and of the ether. We want to understand more completely the structure of atoms and molecules. We want to know the structure of corpuscles and nuclei. We want to understand the interatomic and intermolecular forces. We want to know what determines

the various properties of the different elements. We want to understand the nature of positive and negative charges of electricity. We want to know the nature of electric and magnetic fields and the relation between the two. We want to know a great deal more about the mechanism of radiation.

We must find a way of obtaining power from coal more economically. The direct energy of the sun should be employed and stored for use at night and in winter. The energy of the tides and of the wind must be economically utilized. These and a thousand other problems are waiting for solution.

The ultimate aim of science, as I see it, is to solve the mysteries of nature not only for the purpose of broadening our vision of the external world and for making its forces serve our physical needs, but also in so doing to help guide us to a fuller understanding of our relation to the universe and of the miracle of our existence. May we not ultimately learn something definite about the relation of mind and matter?

We must place no limits to the possibilities of science. Speculation and the imagery of what may lie beyond the present boundaries of knowledge are an incentive to greater effort, and are of real value when given their proper place.

I have called attention to the importance of instruments in scientific progress. I have emphasized the importance of perfecting the instruments, not only with regard to greater precision but also with regard to convenience in operation, so as to enable new ideas to be subjected to experiment with the least possible effort.

The vastness of our field and the interdependence of the different branches make it impossible for any one individual or a small group of individuals to be familiar with all the known processes and instruments for accomplishing definite ends. Our investigations often lead to the determination of some quantity we are not accustomed to measure, and we wish to know at once what is the most practical apparatus to employ. Much time is often wasted in devising an instrument that has already been developed, and inefficient devices are often finally employed unnecessarily. When we consider the large number of investigators concerned and the importance of the work, this is a serious matter. We may obtain help from the catalogs of manufacturers, we may write to some one who is more familiar with such measurements, we may search in various scientific books and magazines, technical handbooks, and reports of the bureaus of standards. Such procedure, however, is wasteful and uncertain, and as has already been stated, often leads to the employment of inferior and more cumbersome methods than is necessary. It is like searching for the meaning of a word from its use in literature, in place of using a dictionary, or like searching for physical constants in the original publications, in place of using compiled tables. It is like these, except that it is much worse. Most instruments and methods are described under the titles of the investigations in which they were first employed, which, in addition, are often published in inaccessible journals.

We need what we may call an *encyclopedia of instruments and methods of research.* This should include materials, methods and processes, as well as individual instruments employed in research in all the sciences. Progress in the development of apparatus is so rapid that it would be necessary to issue a yearly supplement and probably to publish a revised edition every few years. This could be done by some bureau or organization with the cooperation of all scientific men. In the simplest form it could give the apparatus and the different methods for accomplishing each definite purpose, a short statement concerning each instrument, with references to

journals where it is fully described, and all improvements to date. If it was desired to produce a low vacuum, all the known methods and the limitations of each would be at once found in such an encyclopedia. If one wished to measure low pressures, the encyclopedia would call his attention, with references, not only to the McLeod gauge but also to the recently devised molecular gauge which might give more accurate results in those particular measurements. If one wished to maintain a constant temperature at several successive points from the temperature of solid carbonic acid to that of liquid air, he might spend a long time in devising an apparatus, but the encyclopedia would at once refer him to the methods that have been successfully employed. Such a publication would add much to efficiency, and the cost would be small compared to the great service rendered to science.

We also need a *journal of scientific instruments,* in English, devoted entirely to the description of new methods and instruments.

I have often felt the need of both such publications, and I am sure that much energy now wasted would be conserved, and on the whole more worthy contributions to science produced. When once accustomed to such necessities we should wonder how we managed to do without them.

We are entrusted with the responsibility of solving some of the greatest and grandest problems confronting the race. It is our plain duty to be improving conditions for individual and general efficiency. We must point out the needs of science in definite and concrete terms, and must not hesitate to urge upon society that it supply all real physical needs for the proper prosecution of its scientific work.

ANTHONY ZELENY
UNIVERSITY OF MINNESOTA

PSYCHOLOGICAL AND HISTORICAL INTERPRETATIONS FOR CULTURE[1]

THE mere fact that we have in Section H a joint segregation of anthropology and psychology would seem to imply some close functional relation between these sciences. However, the most probable explanation of the phenomenon is to be found in the distinctly anthropological conception of historical association. If one may be pardoned the diversion, I would say that most likely this association is due to the shrewdness of some one in finding a chance to smuggle psychology into the scientific camp. Yet, if one recalls the various annual programs of the section, there comes to mind a considerable number of papers and addresses professing to authoritatively interpret cultural phenomena by the aid of psychological conceptions. So far as I know, the authors of these papers have all been psychologists, rarely has an anthropologist ventured to set the psychologists right. Many of these psychological discussions of anthropological problems have struck the anthropologists as a bit naïve and I have not the least doubt but that for once, the psychologists will in turn get a naïve reaction, because I propose to present reasons for doubting the validity of such psychological explanations for cultural phenomena.

We have a considerable bibliography under the heads of psychology of religion, psychology of art, psychology of sex, and psychology of society. Of these the professional psychologists have the first two almost entirely to themselves, but share the others with the sociologists. In the development of their subjects, the psychologists

[1] Address of the vice-president and chairman of Section H, Anthropology and Psychology, American Association for the Advancement of Science, Columbus meeting, December, 1915.